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ASSESSMENT OF GROUNDWATER VULNERABILITY USING INDEX BASED METHOD. CASE OF SEBAOU RIVER AQUIFER (NORTHERN ALGERIA)

HAOUCHINE A[1], HAOUCHINE F. Z.[1], LABADI A[2],

[1] Laboratoire de Géo-Environnement, Faculté des Sciences de la Terre, USTHB
[2] Laboratoire d'Aménagements Hydrauliques et Environnement, Université de Biskra

ahaouchine@gmail.com

ABSTRACT

The intrinsic vulnerability map of Sebaou groundwater system was drawn as part of a research work developed to characterize and evaluate the pollution risks for the coastal aquifers of northern Algeria. Established using "DRASTIC" model in a Geographical Information System (GIS) environment, this map (in 1/50,000th) shows that the study area is characterized by three vulnerability zones: low (5.4%), moderate (91.9%) and high (2.7%).

The localization, with the same map, of existing and foreseeable potential pollution sources, allows water resource managers and land managers to develop the best choices on regard to the sustainable management of resources and environment.

Keywords: Groundwater, Cartography, Vulnerability, Risk.

INTRODUCTION

The industrial development, apart from the hydrocarbon activities which are in price and volume decreasing, is a major and important asset for generating incomes and creating wealth to Algerian economy [Mowafa, 2011]. On the other hand, agricultural sector is very important because it accounts for 10 % of the country's gross domestic product (GDP) [World Bank, 2015]. Currently, institutions in charge of these sectors proposed ambitious plans aiming to boost the industry and agriculture to become major driving factors to the country's economy (SNAT 2030) [JORA, 2010]. These plans include infrastructures and other development activities which will help to satisfy local needs, and in the long run, national needs and reach thus the food self.

Therefore, it is very important to evaluate the risk and possible effects associated with these projects to the ecosystem. A fundamental environmental system that is likely to be affected by these development projects is the groundwater since demand would likely increase adding thus more stress to the groundwater system [Kura et al. 2014].

Most coastal zones in Algeria rely on groundwater as their primary source of freshwater owing to their topographical and geological nature, in addition to the climatic characteristics [Haouchine, 2015], which make it very difficult for surface water to sufficiently exist. Therefore, it is important to assess and monitor the aquifer system in these zones and how anthropogenic activities influence their quality for sustainability of the groundwater resources [Haouchine, 2015]. However, there is still a wide knowledge gap regarding the hydrogeology of these coastal zones and it is important to determine areas where groundwater is particularly prone to contamination. This will help in the creation of vulnerability maps that can be used by prospective end users such as policy makers and environmental managers among others for groundwater protection or mitigation and remediation measures [Arthur et al. 2007].

CHARACTERISTICS OF THE STUDIED AREA:

The Sebaou River (Fig.1) is one of the largest rivers of Algeria. It goes through the Great Kabylie from the region of Azazga at the east, to the region of Dellys at the west, over about 100 km, and spills in the Mediterranean Sea. The irregular rainfall is fairly consistent and surrounding an annual average of 900 mm. Due to a low permeability of geological formations constituting the watershed (schists, marl, calcareous marl), the dense river network is used to support a significant runoff (Q= 1045hm^3/year, at the outlet of the watershed [Djemaï, 1985].

Figure 1: Situation map of Sebaou River catchment

The valley of this river delimits the surface of the Sebaou alluvial aquifer which is the largest coastal aquifer in the region of the Great Kabylie and which is the main water resources. Protecting its groundwater against agricultural, industrial or urban pollution is one of the major aspects of sustainable development in the region.

GEOLOGICAL AND HYDROGEOLOGICAL FEATURES:

The geological and hydrogeological characteristics of the Great Kabylie were examined by several authors. We can notably cite: Durand-Delga, 1963; Chadrine, 1975; Raymond, 1976; Coutelle, 1979; Bouzar, 1980; Aïgoun, 1981; Djemaï, 1985. According to these authors, the geological structure of the study area consists of a crystallophyllian base, and a sedimentary cover with different formations from the Jurassique to Quaternary, much of which is made up of igneous and metamorphic rocks (Fig.2). It is a depression which corresponds to a wide synclinal basin where the marls of Miocene occupy the larger area**.**

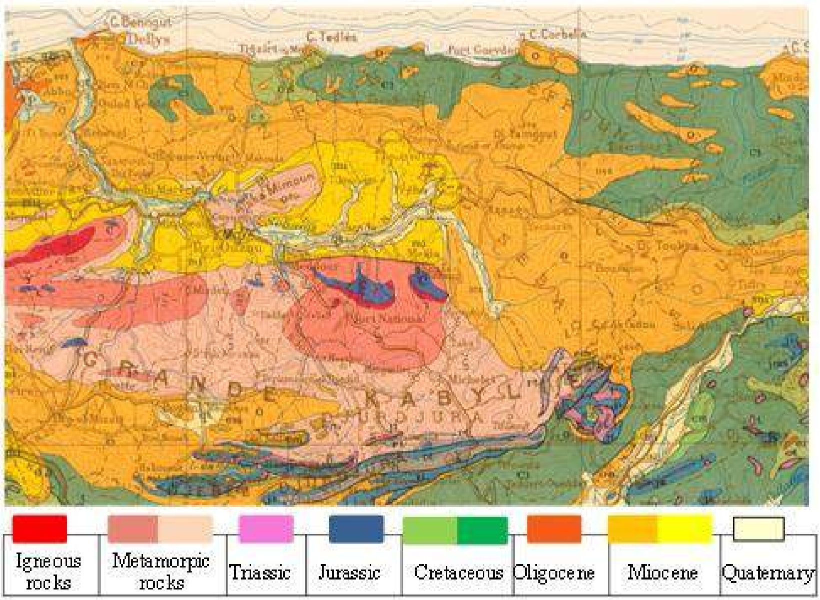

Figure 2: Geological map of the Great Kabylie region 1/500.000 (Cornet & Al. 1952)

The hydrogeological unit defined corresponds roughly to major geological features: the Sebaou Basin is an alluvial filling of a syncline with a NE-SW direction. Porous media includes alluvial and fluvial deposits consist of sand, gravel, silt and clay sediments. These alluviums are arranged in the form of nested and staggered terraces. Generally the valley is narrow, with a width ranging from 100m (Belloua gorge) to 3km (Draa Ben Kheda). With a marly bedrock, the alluvial thickness vary from 15m (in upstream) to 30-50m (in downstream) [Djemaï, 1985].

DATA AND METHODS

The term “vulnerability” was first used in hydrogeological applications in the late 1960’s [Vrba and Zaporozec, 1994] and since then it is commonly used and widely applied to assess protection potential of aquifer systems all over the world.

The notion of vulnerability is based on the assumption that certain areas are less protected by the geological system than others; as such, the less protected areas are more likely to be affected by contaminants [Shirazi et al. 2013]. The vulnerability assessment of groundwater is a way of representing a complex hydrogeological information with a simple map that can easily be applied in many aspects of water management.

Several approaches have been developed to assess groundwater vulnerability. They are usually grouped into three major categories: (1) index and overlay indices, (2) process-based simulation models and (3) statistical approaches [NRC, 1993].

The simplest and most popular among these models are the overlay or index-based methods. They are based on the assumption that a few major parameters largely contribute in groundwater protection or affect groundwater vulnerability, and that these parameters are known and can be evaluated. These methods are generally based on limited basic regional data and usually cover extensive and regional areas. These methods assess groundwater vulnerability qualitatively and using relative scale [Aljazzar, 2010].

Several index-based methods exist, such as GOD [Foster, 1987], SINTACS [Civita, 1994] and EPIK [Doerfliger et al. 1999]. The most commonly used of those methods is DRASTIC which uses a scoring system based on seven hydrogeological characteristics of a region [Aller et al., 1987]. DRASTIC is an acronym of the following seven hydrogeological parameters: i) ***D*** for depth to groundwater, ii) ***R*** for net recharge, iii) ***A*** for aquifer media, iv) ***S*** for soil media, v) ***T*** for topography (slope), vi) ***I*** for impact of the vadose zone media, and vii) ***C*** for hydraulic conductivity of the aquifer. Some parameters are quantitative, while others are related to the media nature. Each of these seven parameters is mapped, usually from existing datasets, although new field data may also be collected for a particular study area. Attributes of each map are rated from 1 to 10 (lowest to highest vulnerability) according to their relative ability to protect the groundwater system from contamination.

Once the map for each parameter is rated from 1 to 10 they are combined to create the final vulnerability index (*Vi*). To do so, each parameter is multiplied by a weighting factor, according to how important that parameter is for overall vulnerability, and all the parameter maps are added together according to:

$$\mathrm{Vi} = D_r * D_w + R_r * R_w + A_r * A_w + S_r * S_w + T_r * T_w + I_r * I_w + C_r * C_w ,$$

Where index r refers to the range and w to the assigned weight. According to Aller et al. 1987, the above equation is: $Vi = 5D_r + 4R_r + 3A_r + 2S_r + 1T_r + 5I_r + 3C_r$. The intrinsic vulnerability values can then be classed or grouped in vulnerability categories such as high, medium, and low. The lowest vulnerability class corresponds to index values less than 79, while the highest class is ascribed to values greater than 200.

RESULTS AND COMMENTS

The DRASTIC model was employed in the aquifer of Sebaou River to evaluate the areas that are more vulnerable to pollution based on pre-assigned rating and weighted to the model parameters depending on the state and nature of each parameter.

❶ Depth to water (parameter D): As water depth decreases, vulnerability increases as contaminants will reach the aquifer quicker and there is less potential for natural attenuation. The data were collected by considering the piezometric campaign of 2013 [ANRH, 2014] that includes 400 measuring points among piezometers, boreholes, and wells (Fig.3).

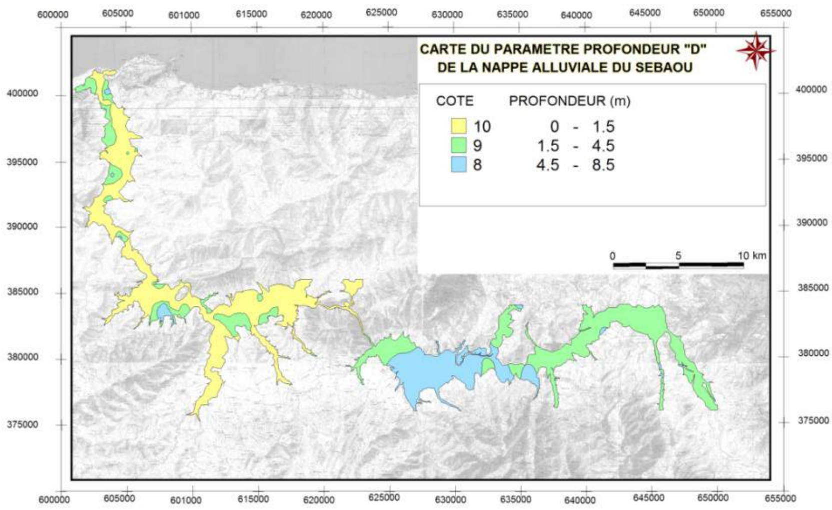

Figure 3: Thematic map of parameter D

❷ Net Recharge (parameter R): the contaminants are being transported by recharge water down to the main aquifer. The map of this parameter was drawn (Fig.4) by considering the value of the calculated effective infiltration through the water balance for the same year (2013) as above.

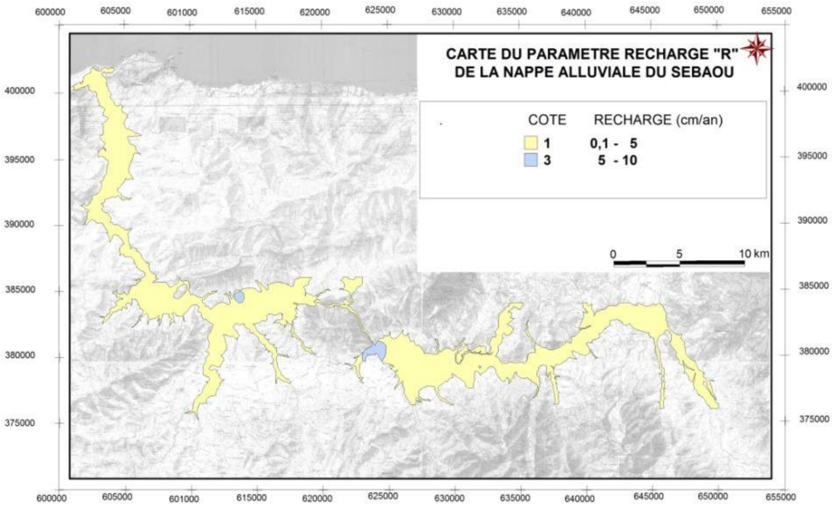

Figure 4: Thematic map of parameter R

❸ Data acquisitions for impact parameters of the vadose zone (parameter I) and nature of the aquifer (parameter A) are made from 113 datasheets drilling. In addition, a hydrogeological map of the area [Chadrine, 1975] served us as frame for setting the ratings in areas where there were data gaps. (Figs. 5, 6).

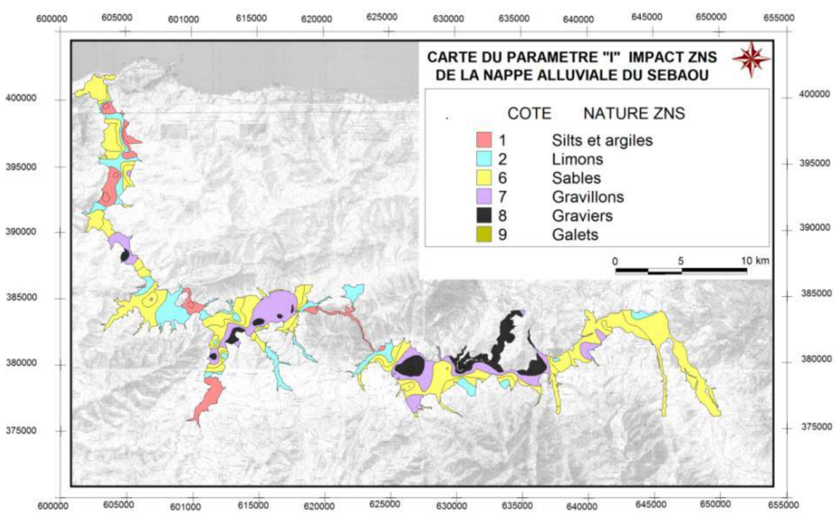

Figure 5: Thematic map of parameter I

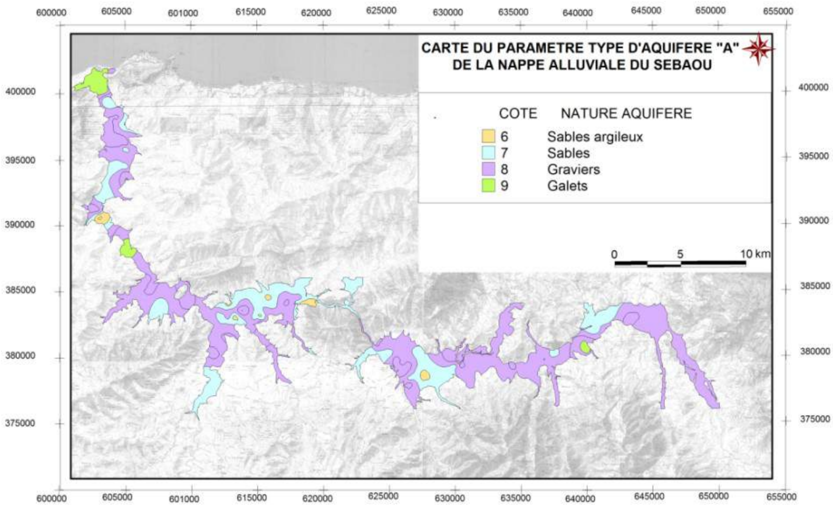

Figure 6: Thematic map of parameter A

❹ The nature of the soil (parameter S) was determined (Fig.7).from the soil survey established at 1/10000th [N. Saadi, 1970] and by the exploitation of raw data relating to the texture of a large number of soil profiles (280) carried out in the plain [N. Saadi, 1970].

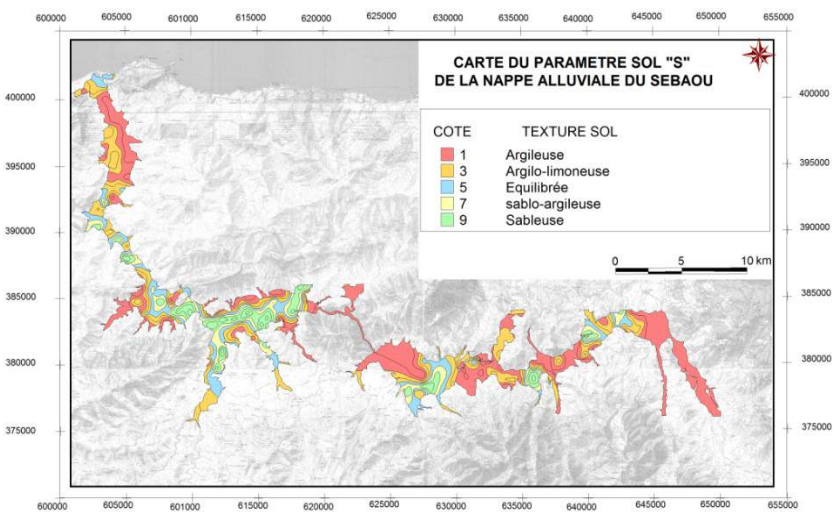

Figure 7: Thematic map of parameter S

❺ To design the thematic map of "T" parameter (Fig.8), we opted for the creation of a DTM (digital terrain model) from topographic maps "1/50000th". This allowed us to automate the calculation of slopes and saved us a tedious calculation work, with a much better result.

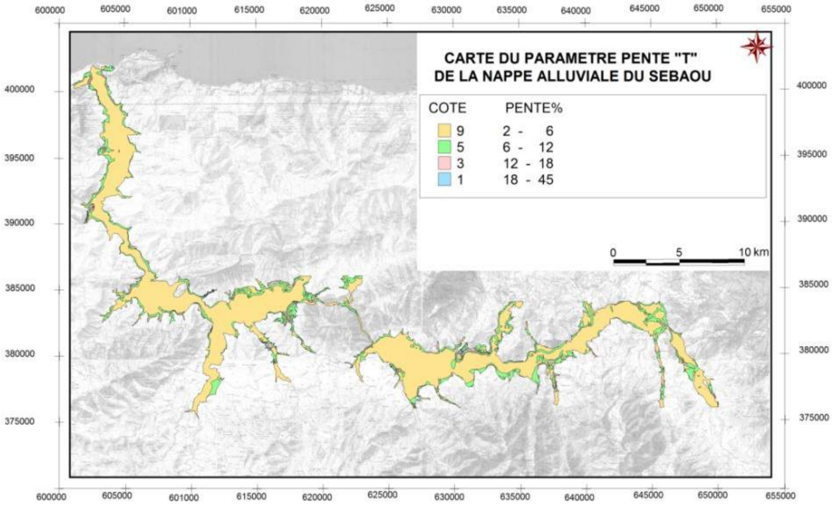

Figure 8: Thematic map of parameter T

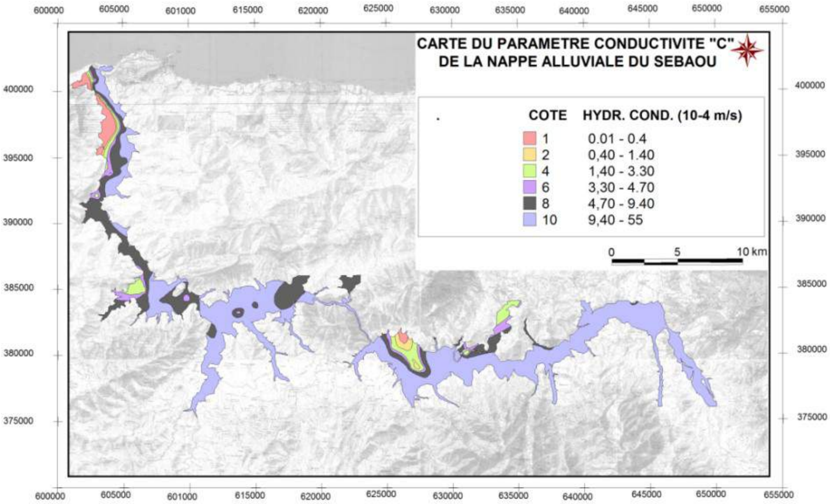

Figure 9: Thematic map of parameter C

❻ To establish the hydraulic conductivity map, we have, in addition to insufficient recent data, used old data from pumping tests performed in the plain [Chadrine, 1975]. We then combined the transmissivity values obtained with the map of isopachs established by the same author to get the "C" parameter (Fig.9).

❼ Drawing the intrinsic vulnerability map:
The final vulnerability map is the result of the superposition of the seven thematic maps. All the parameter layers were then overlaid in GIS environment and weight is assign to each layer based on equation to produce the DRASTIC map. For this purpose a summary table, composed of 172 measurement points, was drawn up. These points correspond almost in their entirety to drillings whom lithological logs allowed us to simultaneously determine both parameters "A" and "I". These drill holes are also the location of measurements of other parameters such as "D" and "C"; which makes them more advantageous operating in developing the final map. Once each point affected its vulnerability index, it becomes easy to create the final map with a suitable interpolation method. In our case, the kriging method responds perfectly to the heterogeneity of the aquifer.

The established final map (Fig.10) shows a range of overall vulnerability indexes ranging from 100 to 179. These values are divided into four classes of vulnerability (IIII, IV, V and VI), representing three degrees of vulnerability: low, medium and high. In a general way, the alluvial aquifer of Sebaou River is moderately vulnerable. Indeed, over 92% of the study area presents values of the DRASTIC index ranging from 119 to 159.

The few low-vulnerability zones (almost 5.4%) are found mainly in the lower Sebaou. The parameters that control these low levels are: a clay soil type, a medium depth of water and a very low hydraulic conductivity.
Although they present small extensions (2.7%), areas with high degrees of vulnerability (159-179), are located in urban areas and near major economic centers; which makes them very sensitive to the risk of pollution. They should therefore be subject to an appropriate control and systematically monitored in order to preserve the region's resources.

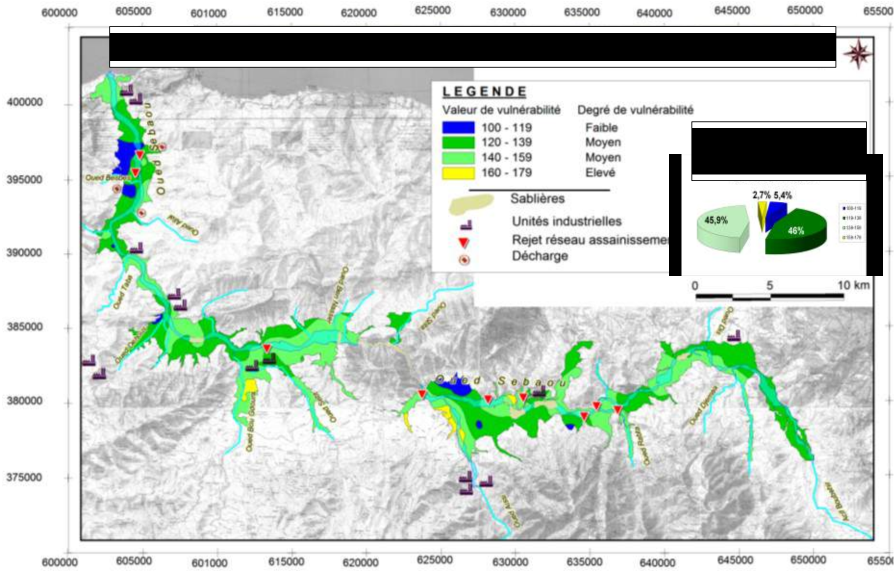

Figure 10: Intrinsic vulnerability map for the aquifer of Sebaou River

CONCLUSION

Intrinsic aquifer vulnerability developed in this study is useful in both source water protection planning and broader groundwater protection frameworks. This vulnerability map can assist local governments, planners, and policy-makers in land use decision-making and sustainable development planning, by identifying sensitive areas and prioritizing areas for further monitoring or protection. These kind of maps are may also be integrated into more complete assessments of groundwater risk, and can be used as an additional layer in management strategies for source water protection areas. Incorporating these maps into groundwater protection frameworks will help protect the quality of groundwater resources for many years to come.

REFERENCES

Aïgoun C. (1982) : Etude hydrogéologique de la plaine alluviale du bas Sebaou. *Mémoire Ingénieur IST, Alger.*

Aljazzar TH. (2010): Adjustment of DRASTIC Vulnerability Index to Assess Groundwater Vulnerability for Nitrate Pollution Using the Advection Diffusion Cell. *Doktors der Ingenieurwissenschaften. Fakultät für Georessourcen und Materialtechnik der Rheinisch-Westfälischen Technischen Hochschule Aachen, Germany.*

Aller L., Bennett T., Lehr J.H., Petty R. , Hacket G. (1987) : DRASTIC: A standardized system for evaluating groundwater pollution in potential using hydrogeologic settings; *United States Environmental Protection Agency, EPA/600/2-87/ 035, 622 p.*

ANRH, (2014): Piezometric campaign in Sebaou River aquifer 2013. *ANRH –National Agency of Water Resources-*

Arthur JD., Wood HAR., Baker AE., Cichon JR., Raines GL. (2007): Development and implementation of a bayesian-based aquifer vulnerability assessment in Florida. *Nat Resour Res 16(2):93–107*

Bouzar I. (1980) : Hydrogéologie du haut Sebaou. *Mémoire Ingénieur IST, Alger*

Chadrine Y. (1975) : Étude hydrogéologique de la nappe de l'oued Sebaou. *Secrétariat d'État à l'Hydraulique, Direction des Études du Milieu et de la Recherche Hydraulique, Service Hydrogéologie, document interne 75.HYG.36, Alger, 72 p.*

Civita M. (1994): Le carte della vulnerabilità degli acquiferi all'inquinamento. Teoria and practica [Aquifer vulnerability maps to pollution. Theory and practice]. *Academy Press, Pitagora*

Cornet A., Dalloni M., Deleau P., Flandrin J., Gautier M., Gourinard Y., Gouskov N., Laffitte R. (1952) : Carte géologique de l'Algérie au 1/500000. *Service de la carte géologique, Alger, 1952.*

Coutelle A. (1979) : Géologie du sud-est de la Grande Kabylie et des Babors d'Akbou. *Thèse de Doctorat es Sciences Naturelles. Université de Bretagne occidentale.*

Djemai M. (1985) : Hydrologie du bassin versant du haut Sébaou ; hydrogéologie des formations alluviales. *Thèse de Doctorat d'Ingénieur, Université de Grenoble 1, 264 p.*

Dörfliger N, Jeannin P-Y, Zwahlen F (1999): Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). *Environ Geol 39(2):165–176.*

Durand-Delga M. (1963) : Essai sur la structure des domaines émergés autour de la méditerranée occidentale. *Geol. Rundsch., Bd.53, pp. 534-535, Paris.*

Foster S (1987): Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In: van Duijvenbooden W, van Waegeningh HG (eds) *Vulnerability of soil and groundwater to pollutants, proceedings and Information. Netherlands Organization for Applied Scientific Research, The Hague, pp 69–86.*

Haouchine A., Haouchine FZ., Labadi A. (2015) : Changements climatiques et Activités anthropiques : impacts sur les aquifères côtiers en Algérie. *Larhyss Journal, ISSN 1112-3680 ; n°24, 2015.*

J.O.R.A. (2010): SNAT2030, Schéma National d'Aménagement du Territoire. Loi n°10-02. *Journal Officiel de la République Algérienne n°61, 49ème année, octobre 2010.*

Kura NU., Ramli MF., Ibrahim S., Sulaiman WNA., Aris AZ. (2014): An integrated assessment of seawater intrusion in a small tropical island using geophysical, geochemical and geostatistical techniques. *Environ Sci Pollut Res 21(11):7047–7064*

Mowafa T. (2011): The mineral industries of Africa -Algerian Report- . *US Geological Survey, 2011, Area reports – International – Africa and the Middle East. USGS Minerals Yearbook 2009, VIII, 368p.*

NRC (1993): Ground-water vulnerability assessment: predicting relative contamination potential under conditions of uncertainty. *National Research Council, National Academy Press, Washington*

Raymond D. (1976) : Evolution sédimentaire et tectonique du nord-ouest de la Grande Kabylie (Algérie), au cours du cycle alpin. *Univ. Pierre et Marie Curie. Thèse Doct. Etat, Sci. Nat. Paris, 156p.*

Saadi N. (1970) : Étude agro-pédologique des plaines alluviales de la vallée du Sébaou (Grande Kabylie). *Secrétariat d'État à l'Hydraulique, Direction des Études du Milieu et de la Recherche Hydraulique, Service Agro-pédologie, document interne EAP 27, Alger, 169 p.*

Shirazi SM., Imran HM., Akib S., Yusop Z., Harun ZB. (2013): Groundwater vulnerability assessment in the Melaka State of Malaysia using DRASTIC and GIS techniques. *Environ Earth Sci 70(5):2293–2304*

Vrba J., Zaporozec A. (1994): Guidebook on mapping groundwater vulnerability. *(IAH Contributions to Hydrogeology 16). Heinz Heise, Hannover.*

World Bank (2015): World Development Indicators: Structure of output. The World Bank. http://wdi.worldbank.org/table/4.2